Strategies for Green Reaction Chemistries
Application of Green Catalysis and Process Intensification

Michael A. Gonzalez Ph.D. Sustainable Chemistry Program – Office of Research and Development;
National Risk Management Research Laboratory; Sustainable Technology Division; Systems Analysis Branch;
gonzalez.michael@epa.gov Phone: (513)-569-7998 Fax: (513)-569-7111

Green Chemistry

- **Pollution prevention** on the molecular level.
  - Environmentally Benign Synthesis
  - Clean Processes
  - Cleaner Production
  - Alternative Pathways
  - Clean Chemistry
  - Benign by Design
  - Design for the Environment
  - Industrial Ecology

Principles of Green Chemistry

Prevention (Overall)
Atom Economy
Less Hazardous Chemical Syntheses
Designing Safer Chemicals
Safer Solvents and Auxiliaries
Design for Energy Efficiency
Use of Renewable Feedstocks
Reduce Derivatives
Catalysis
Design for Degradation
Real-time Analysis for Pollution Prevention
Inherently Safer Chemistry for Accident Prevention

Anastas, P.T., and Warner, J.C., *Green Chemistry: Theory and Practice*, **1998**

Principles of Green Engineering

Inherent Versus Circumstantial
Prevention Not Treatment
Design for Separation
Maximize Mass, Energy, Space, and Time
Output-pulled Versus Input-pushed
Conserve complexity
Durability Not Immortality
Meet Need, Minimize Excess
Minimize Material Diversity
Integrate Local Material and Energy Flows
Design for Commercial "Afterlife"
Renewable Not Depleting

Anastas, P.T. and Zimmerman, J.B., *Environ. Sci. Technol.* 37 (5), pp 94A-101A, **2003**.

Green Catalyst Development

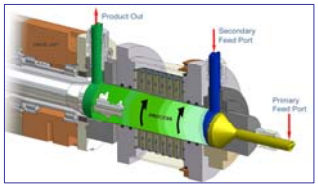
- Design and Development of Bio-mimetic Catalysts for Selective Oxidation of Hydrocarbons.
- Research is Centered on Creating Catalysts Which Operate at Low Temperatures (<125°C) and Pressures (<500psi)
- Intramural Research has Lead to a Collaborative Research Effort with an Industrial Partner (Solutia of Gonzales, Florida)
- Adipic Acid is a commercially important product; precursor to Nylon-6,6
- Potential Benefits Include: Materials and Energy Savings, and Elimination of NO_X generation and Necessary Regeneration to Nitric Acid

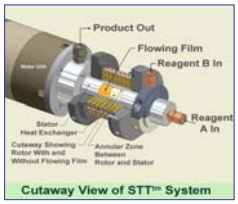
OSCAR: One-Step Cyan to Adipic Acid Research

Current Process	OSCAR Process (EPA)
Two-Steps	One-Step
High Temperatures (170°C)	Low Temperature (125°C); Energy Savings
Boric Acid (Oxidant)	Oxygen (Oxidant)
Nitric Acid Oxidant (NO_x Generation)	Up to 65% Conversion; Materials and Energy Savings
Numerous By-products	Minimized By-product Formation
4-7% Conversion	85% Selectivity to Adipic Acid Yielding Products

Novel Reactors for Green Engineering

- Beginning to Incorporate Green Chemistry with Novel Engineering Technologies
- Cooperative Research & Development Agreement (#02525-03) with Kreido Laboratories of Camarillo, CA
- Evaluation of the Spinning Tube-in-Tube (STT®) Reactor for Sustainable Chemical Reactions
- Incorporates the Aspects of Process Intensification (PI): High Throughput and Small Physical Footprint
- Reactor Creates a Well-stirred Environment Allowing Minimized or Eliminated Mass Transfer Limitations
- Allows for Decreased Contact Times (From Hours to Minutes), Temperatures and Pressures
- Minimization of by-product formation, Increased Conversion and Selectivities
- This CRADA has lead to Collaborative Research Efforts with members of the Industrial Chemical Community (5) and Academic Institutions (2)





The evolution of a green chemical technology into a sustainable technology is the emphasis of this research program. For this to occur it is important the differences between "green" and "sustainable" chemistries be recognized.

Green chemistry can be defined as a chemistry that is focused on design, manufacture, and the use of chemicals that have decreased or no pollution potential.

Whereas **sustainable chemistry** not only includes the concepts of green chemistry, but also expands the definition to include a larger system than just the reaction. **Sustainable chemistry** must also consider the effects of processing, materials, energy and economics. So the question we ask ourselves is "**Can a green process be sustainable**?" This is the question we must keep in mind when developing our technologies for green reaction chemistries.

epascienceforum
Collaborative Science for Environmental Solutions
2005
epa.gov/scienceforum